PLAGUE IN PINE MARTENS AND THE FLEAS ASSOCIATED WITH ITS OCCURRENCE

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Abstract.— Thirteen pine martens (*Martes americana*) were sampled periodically from July 1979 to September 1980 for plague (*Yersinia pestis*) antibodies and their fleas collected and identified. Four individuals were positive for plague antibodies on 8 of 24 sampling occasions. Titer peaks in these individuals occurred simultaneously in early winter but fell to undetectable levels by late spring. A chipmunk flea (*Monopsyllus ciliatus*) was the most common ectoparasite constituting 55% of all individuals collected. Thirty-one percent of all fleas belonged to *Chaetopsylla floridensis*, a species previously unreported in California. The remains of ground-dwelling sciurids (chipmunks, *Eutamias* spp., and ground squirrels, *Spermophilus* spp.) were very common in marten scats during the period preceding elevated titers. For this reason, and the fact that 92% of all fleas collected from martens during this same period were found more commonly on chipmunks and ground squirrels, these rodents were implicated as the source of the martens' exposure to plague.

Plague is an infectious zoonotic disease found primarily in wild rodents in the western United States. Fleas serve as the vector of the disease agent. Carnivores are infected secondarily while feeding upon moribund and dead infected animals (Rust et al. 1971) or from contact with fleas residing in rodent burrows or nests (Eads et al. 1979). Because most carnivores appear to develop only transient clinical signs to plague (Marchette et al. 1962, see Rust et al. 1971, for feline exceptions) and have larger home ranges than rodents, they play an important role in transferring infected fleas to uninfected rodent populations (Eads et al. 1979). Rodent predators also serve as sentinel species for monitoring plague (Poland and Barnes 1979, Messick et al. 1983). Despite their importance, the contribution of rodent predators to the epidemiology of plague is poorly known (Messick et al. 1983). In California, the pine marten feeds primarily on the rodents that are confirmed plague host reservoirs. Plague has been detected in martens elsewhere (Barnes 1982), but little information was available regarding the ecology of the marten population at the site. Presented here are the first records of plague in California pine martens, the flea fauna discovered, and information on marten diets and home ranges.

Materials and Methods

Field work was concentrated in the 40 km^2 Sagehen Creek drainage, located on the eastern side of the Sierra Nevada in Nevada County, California. This area is classified as having "intermediate potential" for epizootic plague (Murray 1964), and evidence of decimation of ground squirrel populations has been documented at nearby Tahoe City (Murray 1971). Thirteen pine martens were captured at least once each from July 1979 to September 1980 and were immobilized with a combined intramuscular injection of ketamine-hydrochloride (Vetalar, 100 mg/ml, Parke-Davis, Detroit, MI) and acetylpromazine maleate (Acepromazine, 10 mg/ml Ayerst Laboratories, Inc., New York, N.Y.). During initial captures, and at several recap tures for those animals trapped often, a toenail was cut to the quick and blood was collected on a paper strip (Wolff and Hudson 1974). These samples were sent to the Plague Branch, Centers for Disease Control, Fort Collins, Colorado, for serological testing. Development of antibody gives evidence of prior infection with plague. Results are reported as a dilution ratio of 1:32 to 1:16,384 with titers $\geq$1:32 considered positive. Fleas were

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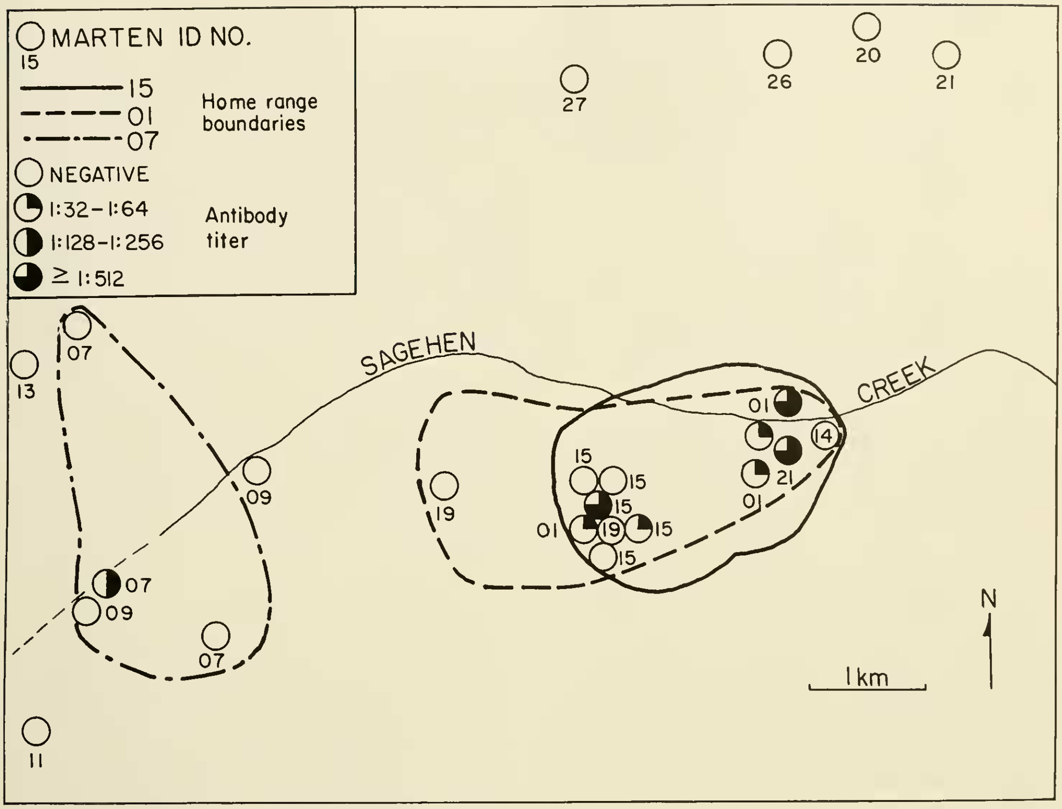

Fig. 1. Marten plague titers and spatial distribution of captures at which a blood sample was collected (Home range boundaries are included for three animals, and each represents the outermost points of 25 to 300 locations).

discovered by close examination of the marten's pelage after brisk brushing and were preserved in 70% ethanol.

Home range information was obtained by monitoring the location of 6 martens fitted with radio-transmitter collars (SB2, AVM Instrument Co., Champagne, IL 61820). Martens were located by approaching the signal on foot with a small hand-held antenna and receiver. Spencer (1981) analyzed the characteristics of marten home ranges in detail, but for purposes of this paper the home range perimeters are defined by the outermost radio locations.

Marten food habits were studied by analyzing scat contents. Hair remains were identified to the most specific taxon possible with the assistance of a reference collection of hairs from mammals collected in the study area and an identification key (Moore et al. 1974). Bone fragments and teeth were also compared to a reference skeleton collection. The volumetric proportions of the contents were estimated visually and multiplied by the scat volumes to determine relative percentages of food items by volume. Additional procedures are presented in Zielinski (1981).

Results

Plague Titers and Flea Occurrence

Four (M01,M07,F15,F21) of 13 martens captured were plague positive on 8 of 24 sampling occasions. Two of these individuals (F15,M01) were radio collared, and their ranges overlapped substantially (Fig. 1). The female, F21, was trapped once within the shared portion of home ranges of the previous two martens. Trapping data suggests that M07 occupied an area exclusive of the other three martens (Spencer 1981).

The antibody titer of three martens (M01,M07,F15) was tested a minimum of three times between August 1979 and May

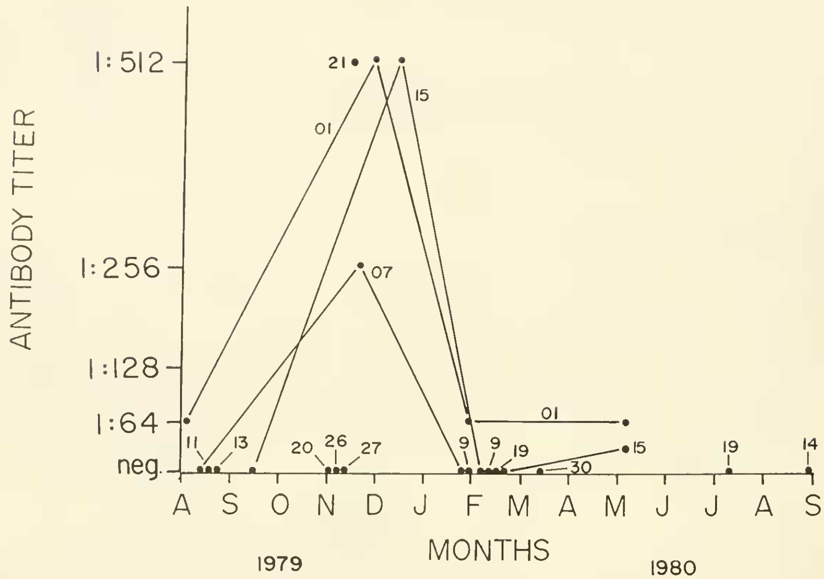

Fig. 2. Monthly distribution of marten plague titers from August 1979 to September 1980.

1980 (Fig. 2). Each expressed a titer peak of 1:256 to 1:512 in November or December. Although sampled only once, F21 expressed a titer of 1:512 during this time as well. Three other martens sampled during this same period, however, were negative.

Seventy fleas were collected from 13 martens (6F:7M) on 20 occasions (Table 1). Seven species in five genera were identified. Fleas were collected from all regions of the marten's body and during all seasons of the year. The flea, *Chaetopsylla floridensis*, is monoxenous to martens and was collected for the first time in California during the present study. All other fleas found occur more commonly on rodents. *Monopsyllus ciliatus*, a chipmunk flea, was the most common represented by 39 individuals. Flea species were easily distinguishable as warm or cold season parasites on martens. *Monopsyllus wagneri*, *Megarthoglossus* sp., and *Orchopeas nepos* were typical winter fleas collected between 5 November and 13 March. *Monopsyllus eumolpi*, *Monopsyllus ciliatus*, and *Oropsylla idahoensis* were collected only between 5 May and 5 September.

Food Habits

Thirty-six different food items were identified from 300 scats. Mammals composed 76.1% of the total annual diet, reaching a high of 87.9% during the winter. Rodents formed the largest portion of the mammal category, representing 62.1% of the annual diet and 64.2% during the summer. Because rodents are the primary hosts of plague-bearing fleas, the discussion of marten food habits will focus on these prey. A more complete description of marten food items at Sagehen is summarized by Zielinski et al. (1983).

Microtines (the montane vole, *Microtus montanus*, and the long-tailed vole, *M. longicaudus*) were the most common rodent prey, composing 23.7% of the annual diet (Table 2). Their use by martens was not confined to a particular season.

Most other mammalian prey were distinguished as either summer or winter food items. Chipmunks, golden-mantled ground squirrels (*Spermophilus lateralis*), California ground squirrels (*S. beecheyi*), and Belding ground squirrels (*S. beldingi*) were taken only during the snow-free period of the year. Chipmunks and golden-mantled ground squirrels were the most frequent prey, averaging 33.3% of the diet during this period. Conversely, the chickaree (*Tamiasciurus douglasii*), snowshoe hare (*Lepus americanus*), northern flying squirrel (*Glaucomys sabrinus*), and deer mouse (*Peromyscus maniculatus*) were primarily winter foods.

DISCUSSION

Titer Variance

Although most martens expressed a peak in antibody titer in late fall or early winter, antibodies were not detected in several individuals. Martens M20, M26, and M27 each had negative titers during November when martens M01, M07, F15, and F21 exhibited their highest titers. Several explanations for this result are possible. First, the three martens in which antibodies were undetected were all captured in the extreme northern boundary of the study area, at least 3 km from other marten captures. Plague may have either been distributed patchily within the study area and the martens in question lived within an uninfected area, or plague may have been moving through the region in a northerly direction and had not yet infected rodents in the area in which the martens foraged. Also, these three martens may have had recent exposure to plague and antibodies may have been too low to detect using the Nobuto strip technique. Finally, there may be a high degree of variation in the reaction of individual martens to plague exposure. Little is known of antibody response in martens, but responses have been shown to vary greatly from one individual to another in other predators and rodents (Barnes 1982).

Inferring Predator-Prey Interactions via Flea Fauna

Although the identification of marten fleas broadened the scant records of marten ectoparasite fauna (de Vos 1957, Eads et al. 1979), these data were also useful in deducing interactions between marten and their prey. Fleas are relatively host specific, parasitizing a subfamily, genus, or species of host (Pollitzer 1954:638). Because martens acquire fleas while consuming prey or searching burrows and nests, it is possible to infer the type of prey the martens hunt on the basis of their ectoparasite fauna. This information is useful in verifying food habits information obtained by scat analysis and in documenting exposure to rodents that are known plague reservoirs.

TABLE 1. Fleas recovered from martens at Sagehen Creek from July 1979 to September 1980.

Species	Date	M	F	Usual host(s)
Megarthroglossus sp.	24 Jan		1	Cricetine rodents (probably deer mouse)[b]
Monopsyllus wagneri	1 Feb		1	deer mouse[b]
M. ciliatus	5 May	1	2	chipmunks (except yellow pine)[b]
	4 June	3	8	
	24 June		1	
	29 Jul	2	3	
	4 Aug	3	6	
	17 Aug		2	
	18 Aug	1	1	
	20 Aug	2	2	
	5 Sep	1	1	
M. eumolpi	26 Jun	1		yellow-pine chipmunk[b]
	4 Aug	1		
	20 Aug	1		
Orchopeas nepos	5 Nov		1	chickaree[b]
	13 Mar		1	
Oropsylla idahoensis	4 June		1	golden-mantled ground squirrel[a]
	29 Jul	1		
Chaetopsylla floridensis	11 Nov	2	3	pine marten[b]
	29 Nov	2		
	16 Dec		1	
	24 Jan	2	4	
	2 Feb		1	
	11 Feb	3	2	
	13 Feb	1	1	
Totals		27	43	

[a]Barnes (1982)
[b]B. Nelson (pers. comm.)

Monopsyllus wagneri (deer mouse flea), *Megarthoglossus* sp. (mouse flea, most likely deer mouse nest flea) (Nelson, pers. comm.), and *Orchopeas nepos* (chickaree flea) were collected from martens during winter. The association of martens with these rodent hosts is also supported by their abundant remains found in scats of this period. Conversely, the fleas *Monopsyllus eumolpi*, *M. ciliatus*, and *Oropsylla idahoensis* were collected from martens during the snow-free period and are normally found on the yellow-pine chipmunk, other chipmunks, and the golden-mantled ground squirrel, respectively. Again there is a similarity between the flea's usual hosts and the marten's summer diet as determined by scat analysis.

Despite these associations, predicting marten food habits from flea species occurrence has several drawbacks. Species that are common prey may not be represented by their fleas. In this study, the fleas of snowshoe hares and voles were not found on martens. This is especially unusual for voles, considering their importance in the diet throughout most seasons. Eads et al. (1979) also found lagomorph fleas absent from martens in Colorado despite their abundance in a free-living state. In addition, the life cycle information necessary to determine the duration of flea persistence on a marten is lacking. Inferences about seasonal marten diets are inconclusive without this knowledge. Finally, the host specificity of many fleas is unknown. As the array of suitable hosts increases, the value of a flea in predicting specific prey eaten or hunted diminishes.

Inferring Plague Hosts via Flea Fauna and Plague Titers

Martens include many rodent species in their diet, but most evidence implicates ground-dwelling sciurids (chipmunks and ground squirrels) as the source of the marten's exposure to plague. Members of the genera *Eutamias* and *Spermophilus* are common hosts of plague-bearing fleas throughout the range of the disease in North America (Barnes 1982), and plague has been demonstrated in all species within these genera that occur at Sagehen Creek (Nelson 1980). Similarly, seasonal changes in seropositive badger (*Taxidae taxus*) titers were found to correlate with predation on the plague-susceptible Townsend ground squirrel (*Spermophilus townsendi*) in Idaho (Messick et al. 1983). Members of other genera upon which marten prey at Sagehen have been shown to be either somewhat refractory to the disease (i.e., *Tamiasciurus*, Nelson 1980, *Peromyscus* and *Microtus*, Bacon and Drake 1958, Hudson and Kartman 1967, Hubbert and Goldenberg

TABLE 2. Mammalian prey of the pine marten at Sagehen Creek 1979–1980, presented as total volume of 300 scats.

	1 Dec–1 Mar	2 Mar–25 Apr	26 Apr–1 July	2 July–1 Sept	2 Sept–30 Nov	Total
No. scats	91	61	76	25	47	300
No. items	138	96	125	59	84	502
Prey items						
Microtus spp.	37.4	5.2	33.2	4.5	18.3	23.5
Tamiasciurus douglasii	13.9	29.8	3.5	1.1	3.1	11.3
Spermophilus lateralis		1.8	13.9	25.2	10.9	8.3
Lepus americanus	18.8	10.0	0.7	1.9	0.9	7.7
Eutamias spp.	2.7		8.6	18.8	3.0	5.4
Glaucomys sabrinus	5.6	13.1			2.0	4.6
Peromyscus maniculatus	8.5	7.8	1.0		2.1	4.5
Scapanus latimanus		3.2	5.0	5.9	7.2	3.5
Thomomys monticola	2.3		2.1	7.2	0.2	2.0
Sorex spp.			4.0		3.2	1.5
Odocoileus hemionus		0.4	1.5		5.6	1.2
Spermophilus beldingi				4.7		1.0
Spermophilus beecheyi		0.5		0.9	3.0	0.2
Unidentified *Spermophilus*			3.5			1.0
Marmota flaviventris			0.2			0.1
Erethizon dorsatum		0.1				0.1

1970) or data on their susceptibility are lacking (i.e., *Glaucomys, Thomomys*) (Nelson 1980).

The time of the year that martens were seropositive also attests to their interactions with ground-dwelling sciurids. The highest titers occurred during November and December. Nevertheless, these peaks represent the decline phase of a higher response peak (probably greater than 1:1080) that would have been evident had these individuals been sampled in September or October (B. Nelson, pers. comm.). If marten antibody responses are similar to those in mongoose (*Herpestes auropunctatus*), these titer peaks typically should occur about one month after exposure (Meyer et al. 1965). Thus, if this assumption is correct, martens most likely contracted plague in August or September. This is in agreement with the annual escalation of plague activity during late summer in northern California (B. Nelson, pers. comm, Murray 1971) and occurs when martens are feeding primarily on chipmunks and ground squirrels. Because these rodents as a group are highly susceptible to plague, and because they compose a much greater component of the marten diet in northern California than elsewhere (Zielinski et al. 1983), pine martens may play a greater role in the ecology of plague in California than elsewhere.

Acknowledgments

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